



Measurement of γ -distribution and neutron dose with TEPC

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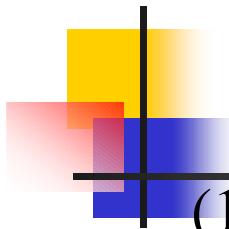
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(1)Experiment at FNL

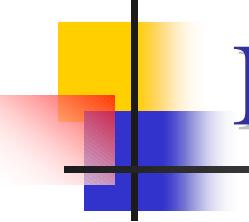
- The response of the TEPC against the monoenergetic neutron
 - y-distribution
 - Neutron detection efficiency
 - Comparison to the kerma for A-150

(2)Experiment at TIARA

- The Response against the more high-energy quasi-monoenergetic neutro
 - y-distribution
 - Absorbed dose and dose equivalent

(3)Shielding experiment at HIMAC

- y-distribution
- Absorbed dose and dose equivalent
- Attenuation length

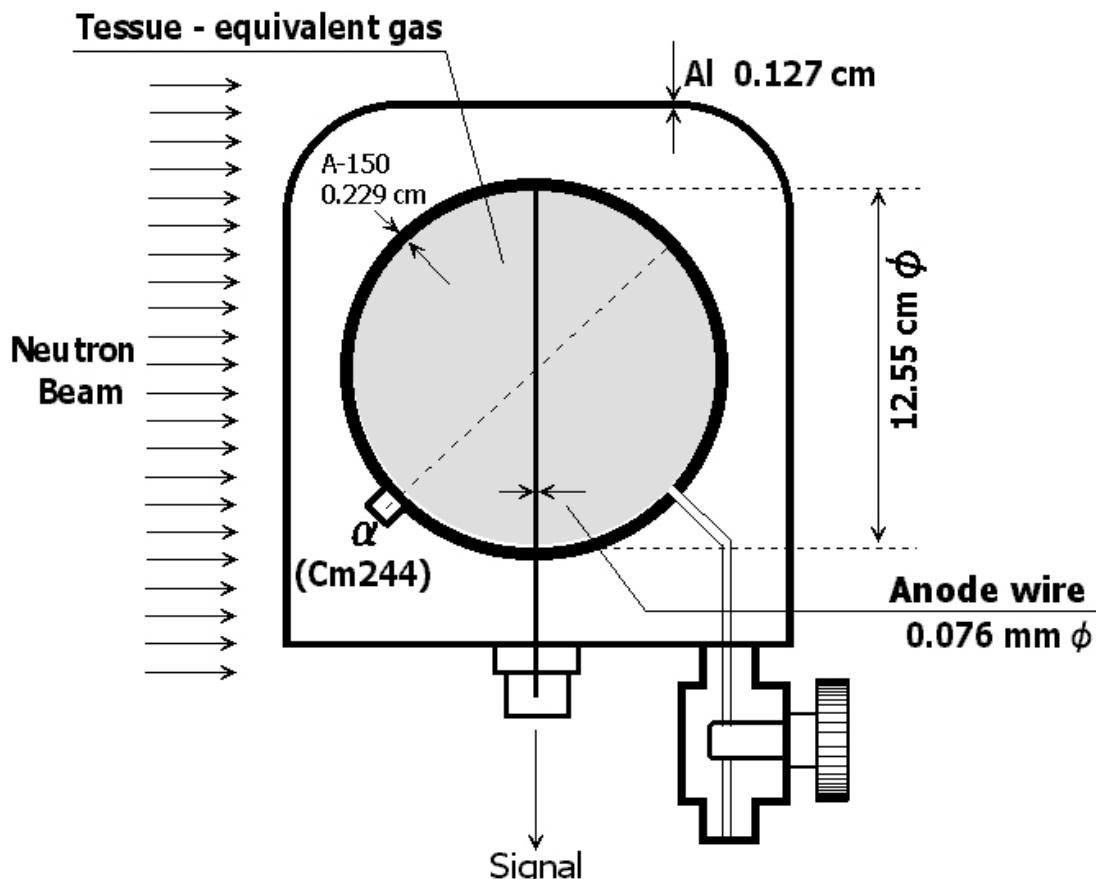


Introduction

- Shielding design is very important for the construction of an intense high-energy accelerator facility, since massive shields for high-energy neutrons having strong penetrability are required and then the cost for the radiation shielding contributes a considerable part of the total cost.
- The TEPC (Tissue Equivalent Proportional Counter) is the spherical proportional gas counter filled with low-pressure gas (propane base, 10 torr) to simulates the cell (tissue, 760 torr) of about several micro-meter. The neutron absorbed dose can evaluate quantitatively by measuring the energy deposition of charged particle in this microscopic cavity.

Tissue Equivalent Proportional Counter

LETSW5 : Far West Technology



A150 plastic

H 10.1, C 77, N 3.5, O 5.2
Ca 1.8, F 1.7 (w%)

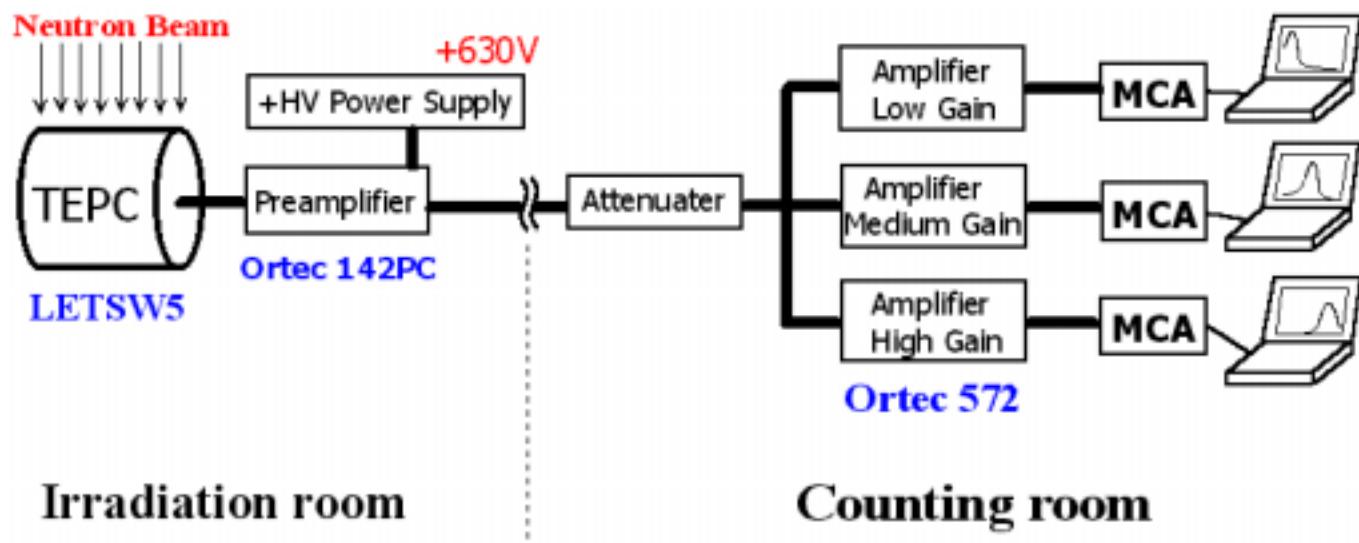
Tissue Equivalent gas

C₃H₈ : 55, CO₂ : 39.4
N₂ : 5.5 (%)

$$D \cdot \rho \cdot \frac{P}{760} = d \times 10^{-4} \cdot 1 \cdot 1$$

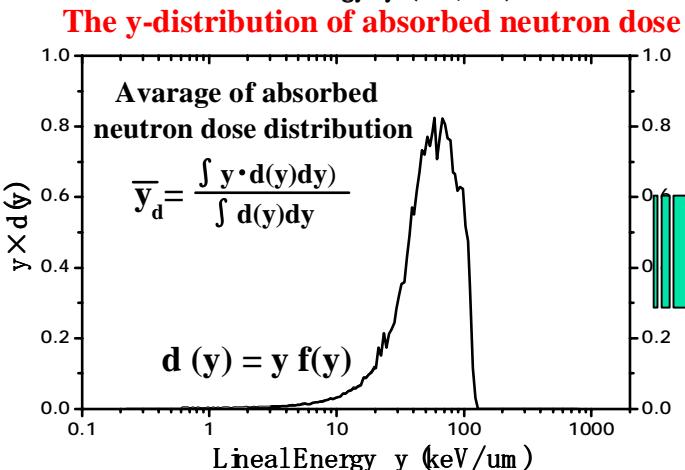
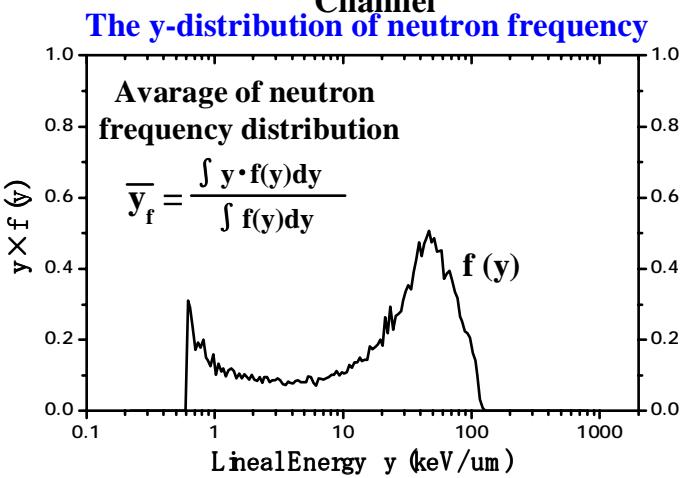
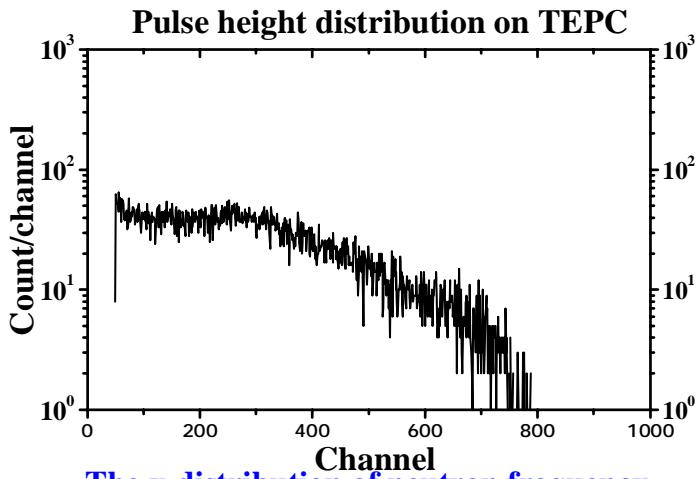
$$P = 10 \text{ torr}, \rho = 1.814 \text{ g/l}$$

Block diagram of measuring circuits



$$y = h \left(\frac{\delta\alpha}{h\alpha} \frac{3}{2d} \right) G$$

- y : Lineal Energy [keV/ μ m]
- $\delta\alpha$: Energy deposition of α particle [keV]
- $h\alpha$: Peak channel of α particle
- h : channel
- d : Diameter of tissue equivalent cavity [μ m]
- G : Gain ratio

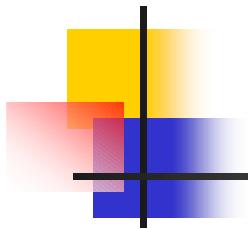


The data analysis

- The energy calibration with inside α -source
- Convert the x-axis into logarithm scale
- Normalize the total area into 1

- Convert the y-axis into absorbed neutron dose with multiplying x-axis and y-axis
- Normalize the total area into 1

- Proton events from neutrons
 - $15\text{MeV} < E_n : \text{under } 10 \text{ keV}/\mu\text{m}$
 - $8\text{keV} \sim 15\text{MeV} : 10 \sim 130 \text{ keV}/\mu\text{m}$
- Heavy ion events from neutrons
 - $5\text{MeV} < E_n : 130 \sim 2000 \text{ keV}/\mu\text{m}$



The absorbed neutron dose

$$D = J \frac{l}{m} \sum_i y_i N_i$$

D : Absorbed neutron dose [Gy]

J : The conversion constant from eV into J

l : Mean chord length of TE-cavity ($=2d/3$)

y : Lineal energy [keV/ μ m]

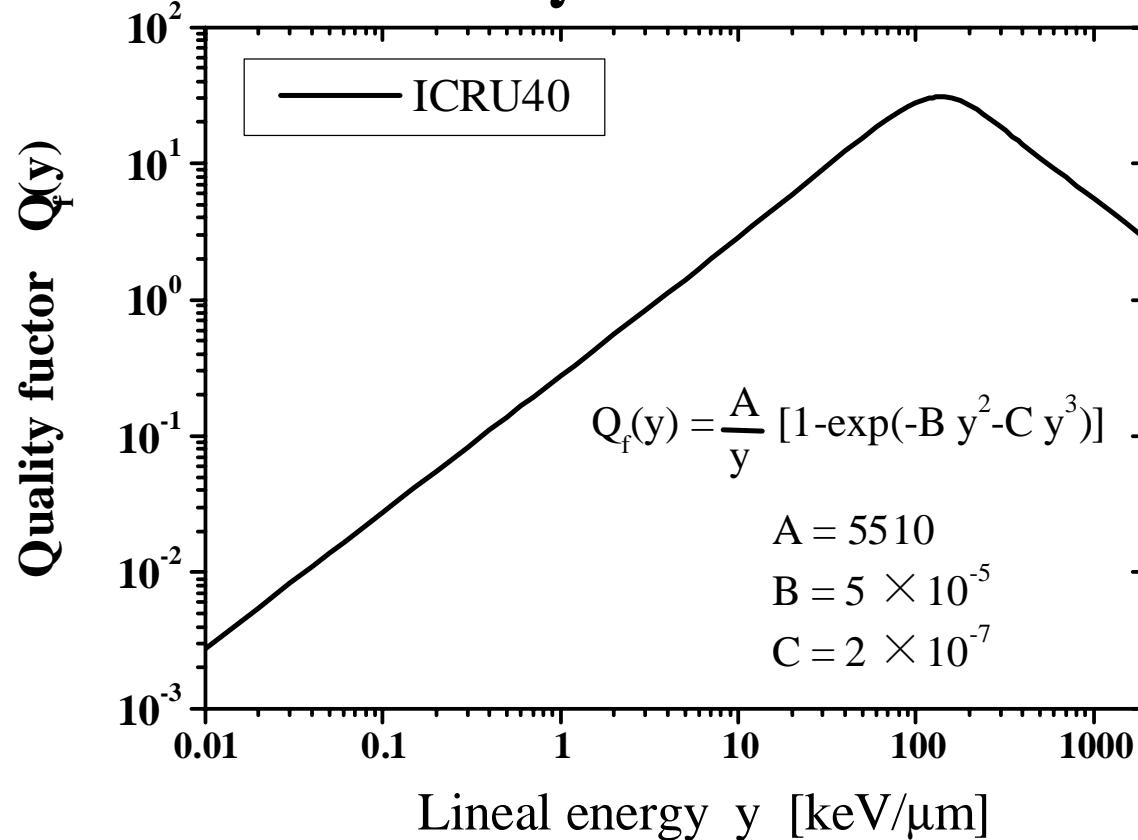
i : The lineal energy bin number

N : The number of events at i bin

m : Mass of the sealed TE-gas [kg]

The neutron dose equivalent

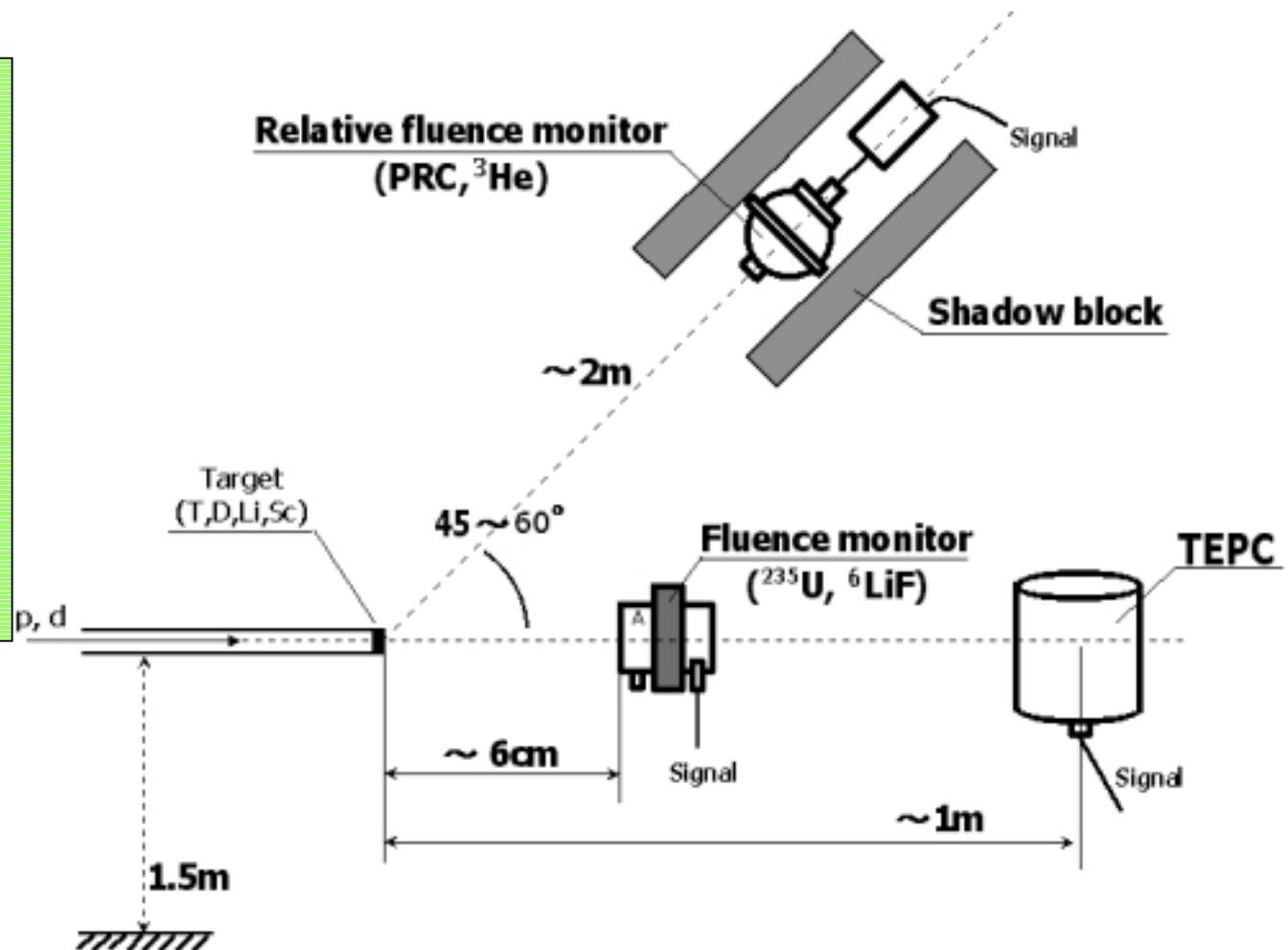
$$H = \int d(y)Q_f(y)dy$$



(1) Experimental arrangement at FNL

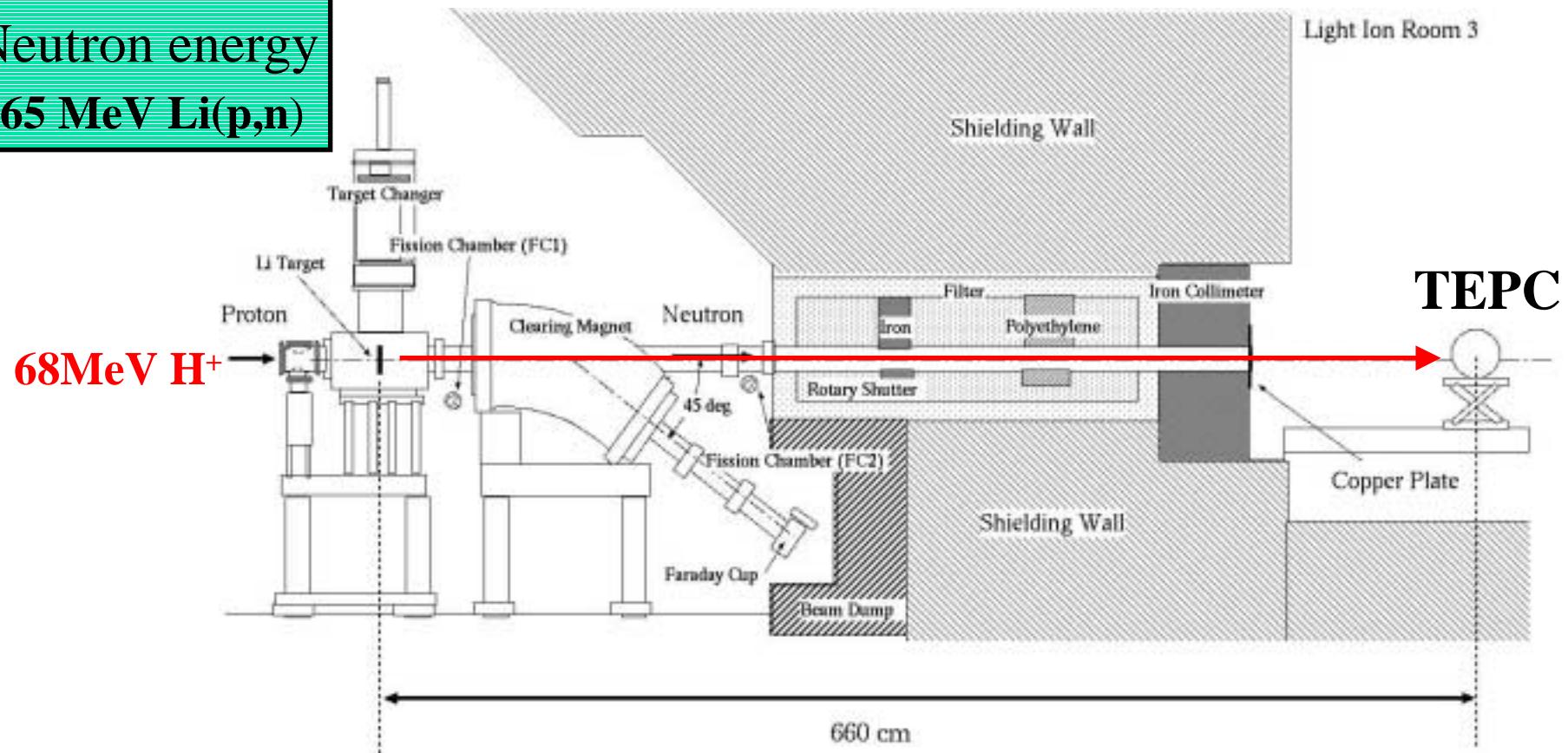
Neutron energy

8 keV	$^{45}\text{Sc}(\text{p},\text{n})^{45}\text{Ti}$
250 keV	$^7\text{Li}(\text{p},\text{n})^7\text{Be}$
550 keV	$^7\text{Li}(\text{p},\text{n})^7\text{Be}$
1 MeV	T (p,n) ^3He
2 MeV	T (p,n) ^3He
5 MeV	D (d,n) ^3He
6 MeV	D (d,n) ^3He
15 MeV	T (d,n) ^4He



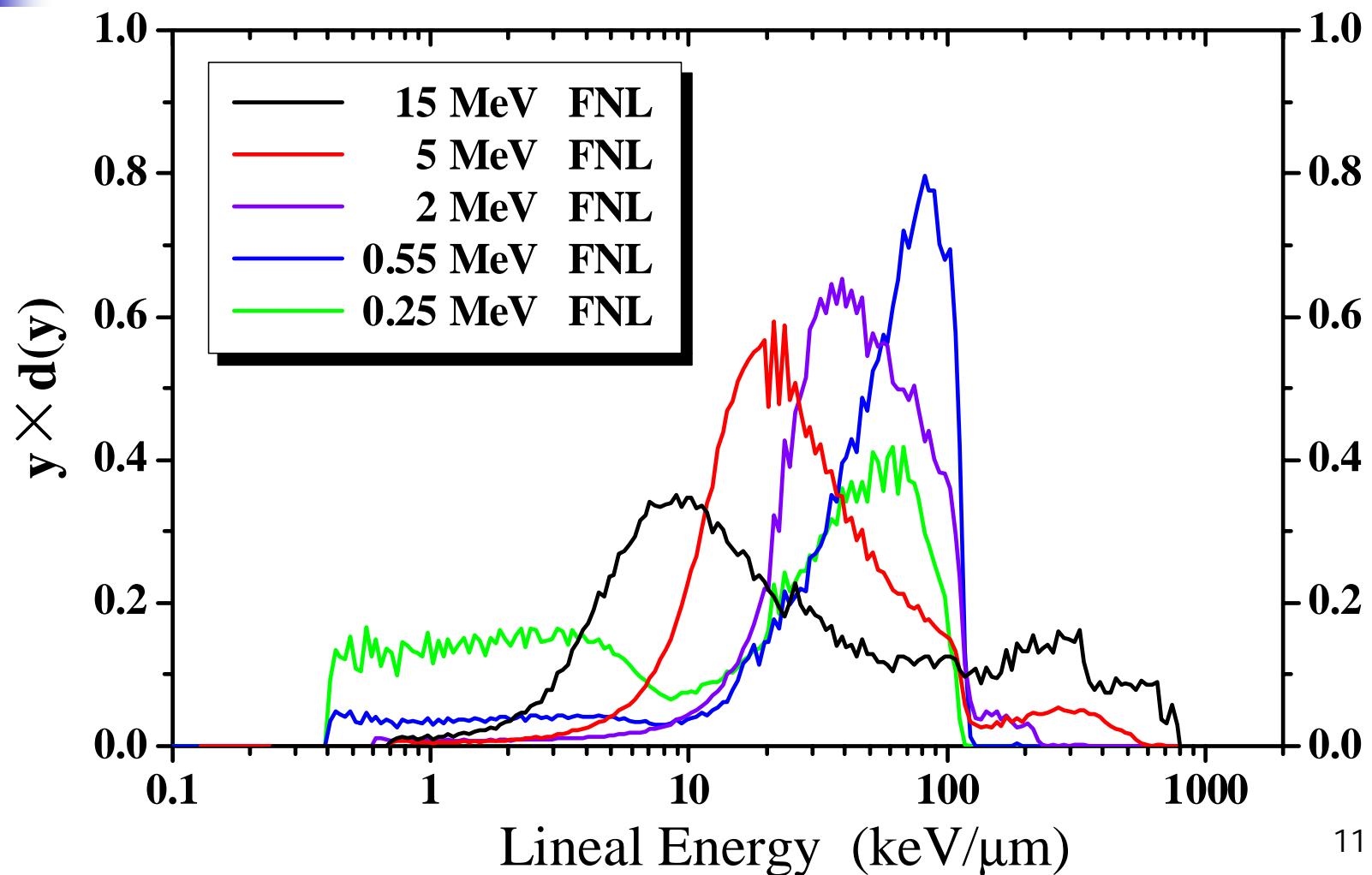
(2) Experimental arrangement at TIARA

Neutron energy
65 MeV Li(p,n)



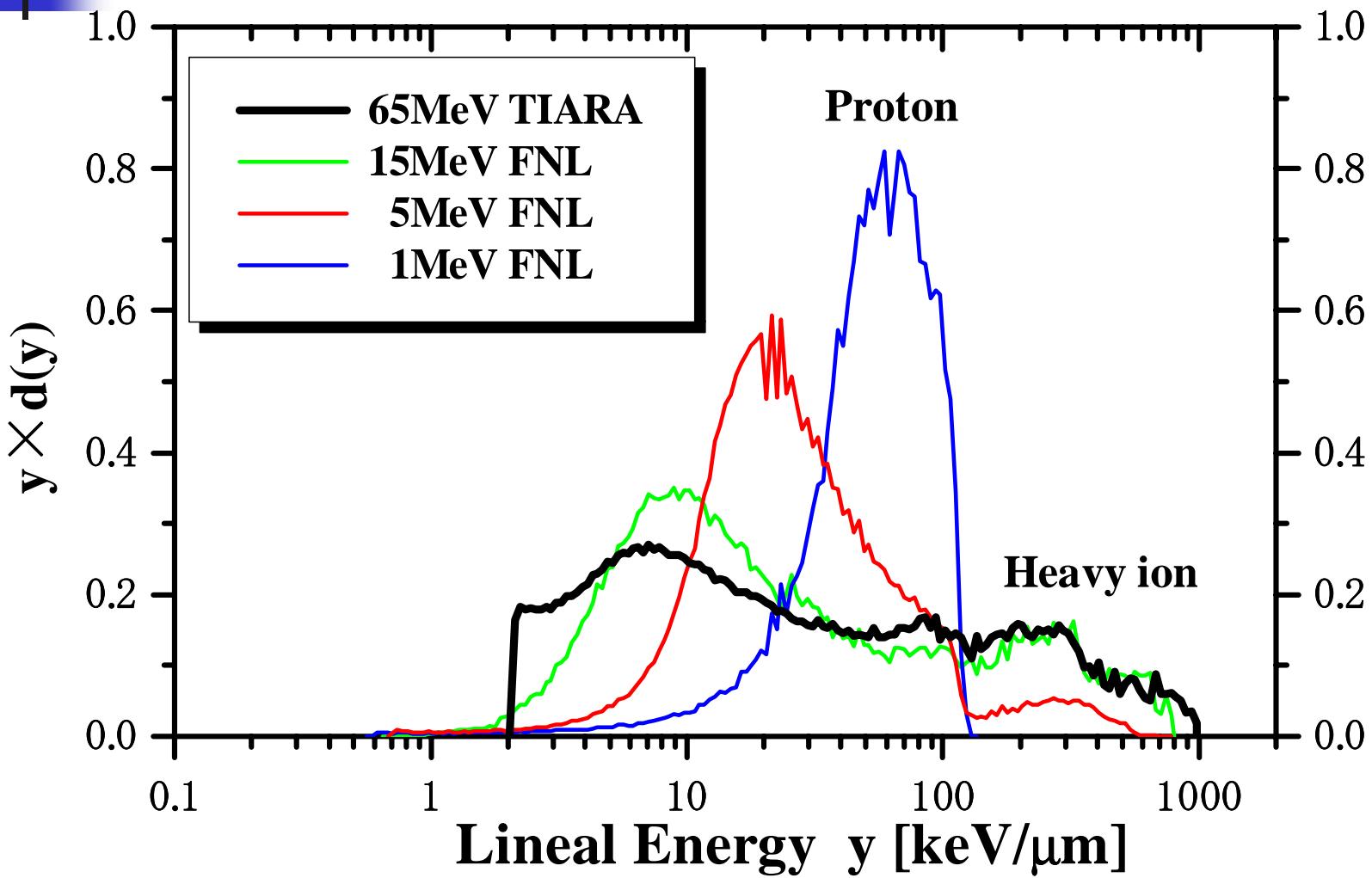
Results(1)

The y-distribution of absorbed neutron dose against the monoenergetic neutron

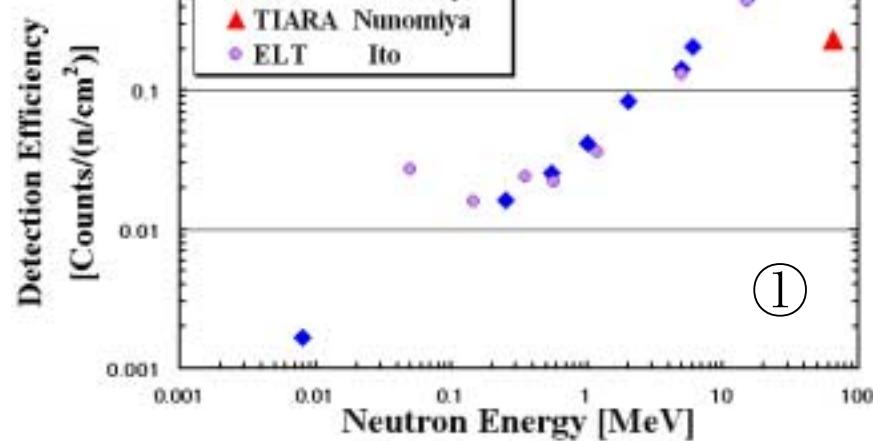


Results(1-2)

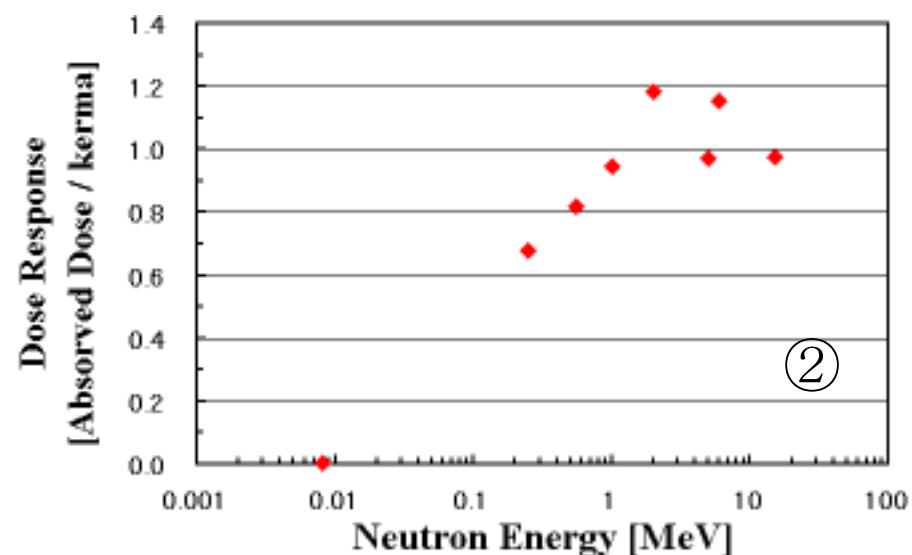
The comparison of y -distribution



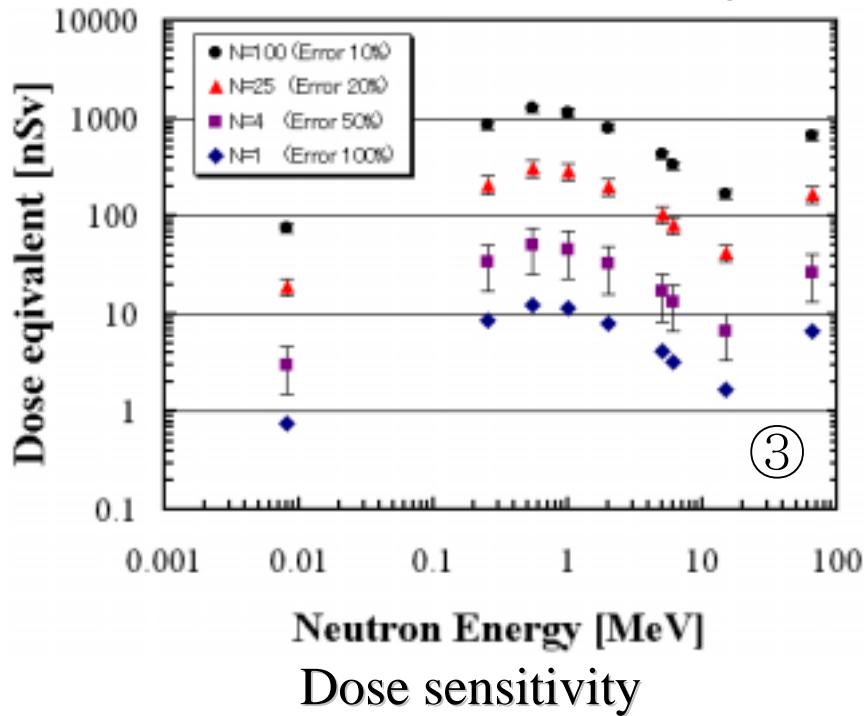
Results(1-2)



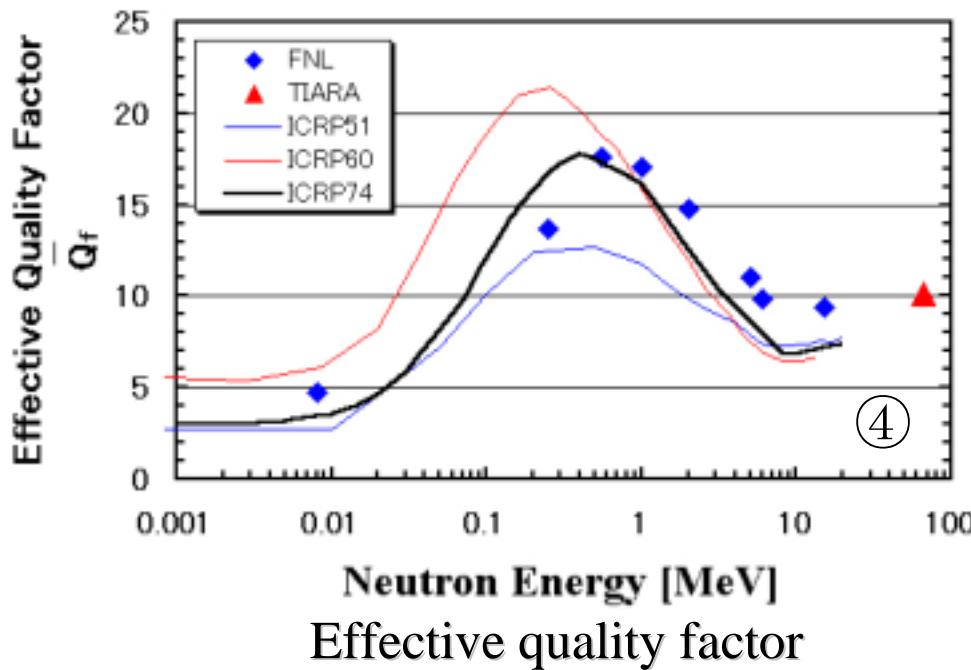
Neutron detection efficiency



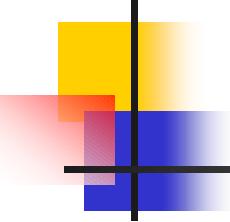
The ratio of dose equivalent and kerma



Dose sensitivity



Effective quality factor



Shielding experiment

The neutron sensitivity characteristic were obtained

Neutron : 8 keV – 65 MeV



Measurement at the unknown radiation fields

Behind the **concrete** or **iron** shield

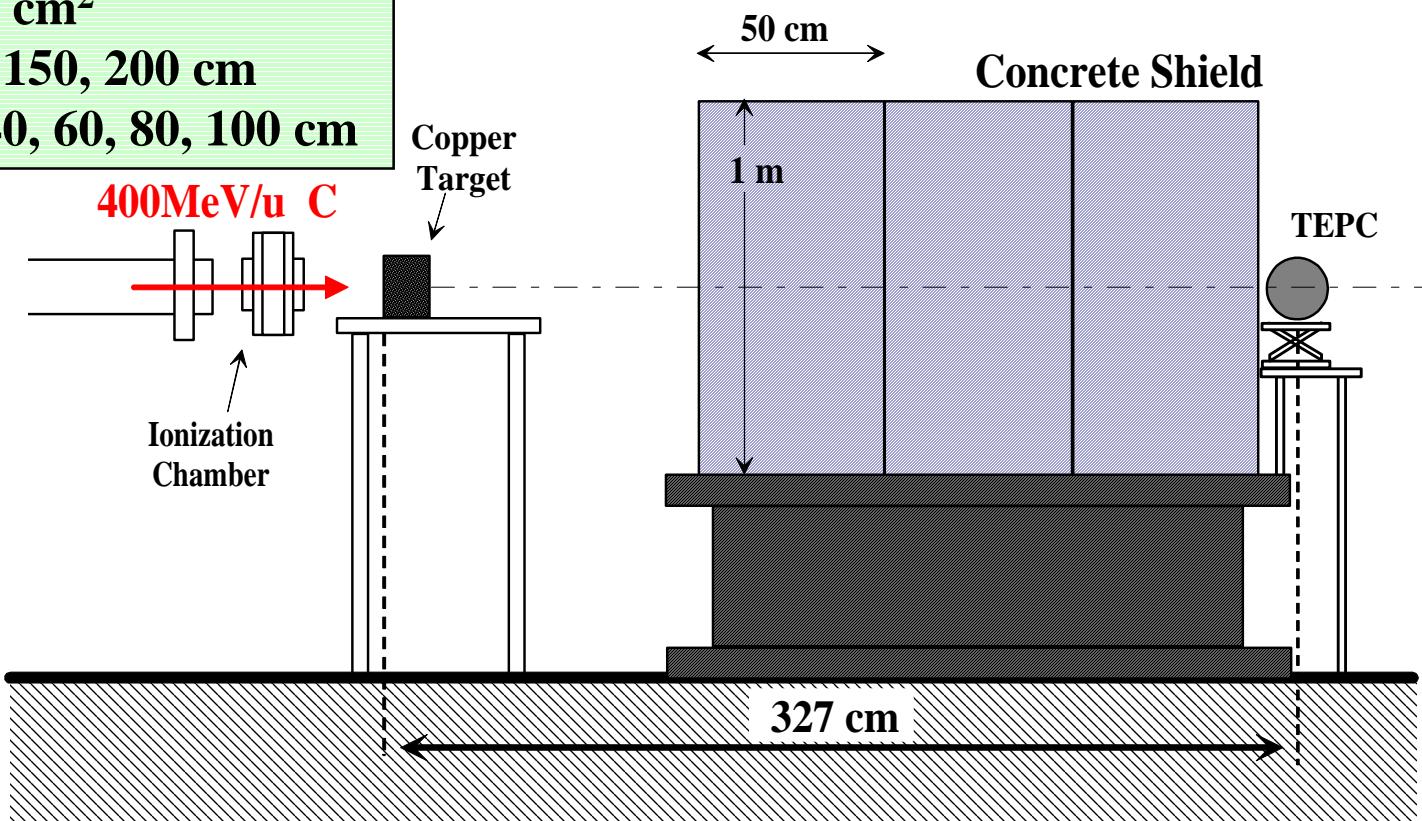
- y-distribution
 - Neutron dose
- Attenuation length

(3) Experimental arrangement at HIMAC

Shield $100 \times 100 \text{ cm}^2$

Concrete :50, 100, 150, 200 cm

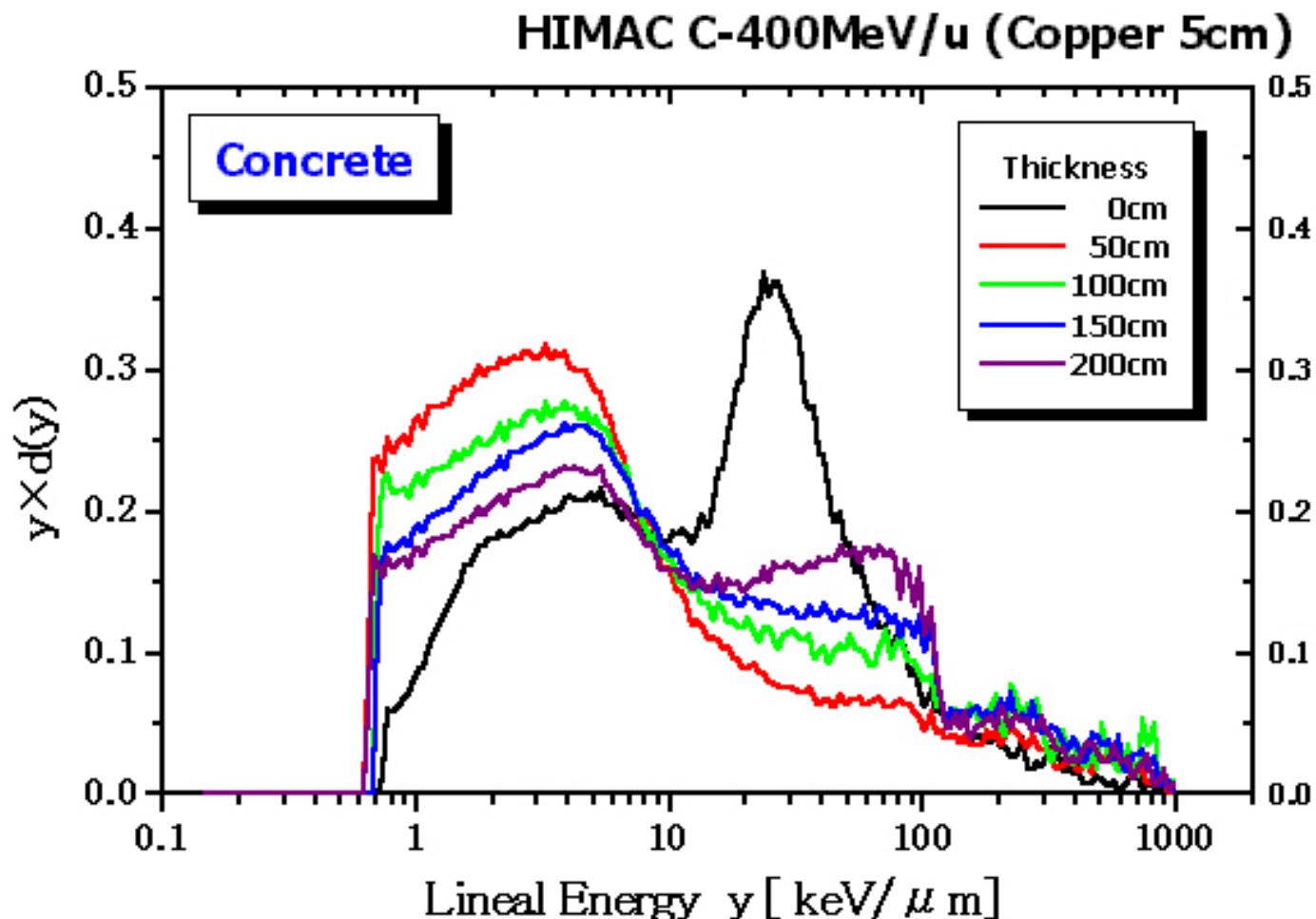
Iron :10, 20, 40, 60, 80, 100 cm



HIMAC : Heavy Ion Medical Accelerator in Chiba of
NIRS

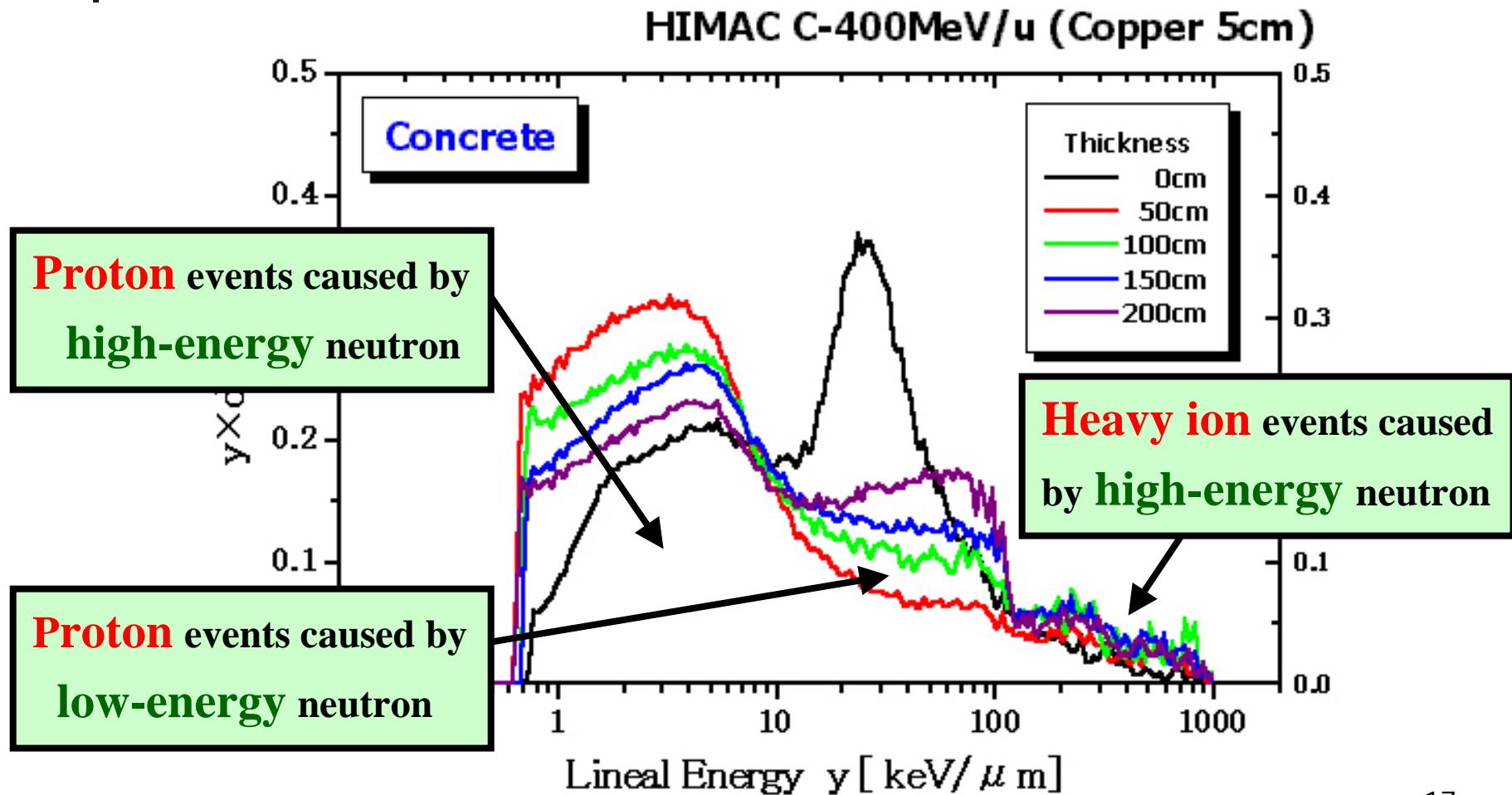
Results(3)

The y-distribution of absorbed neutron dose behind the **concrete** shield



Results(3)

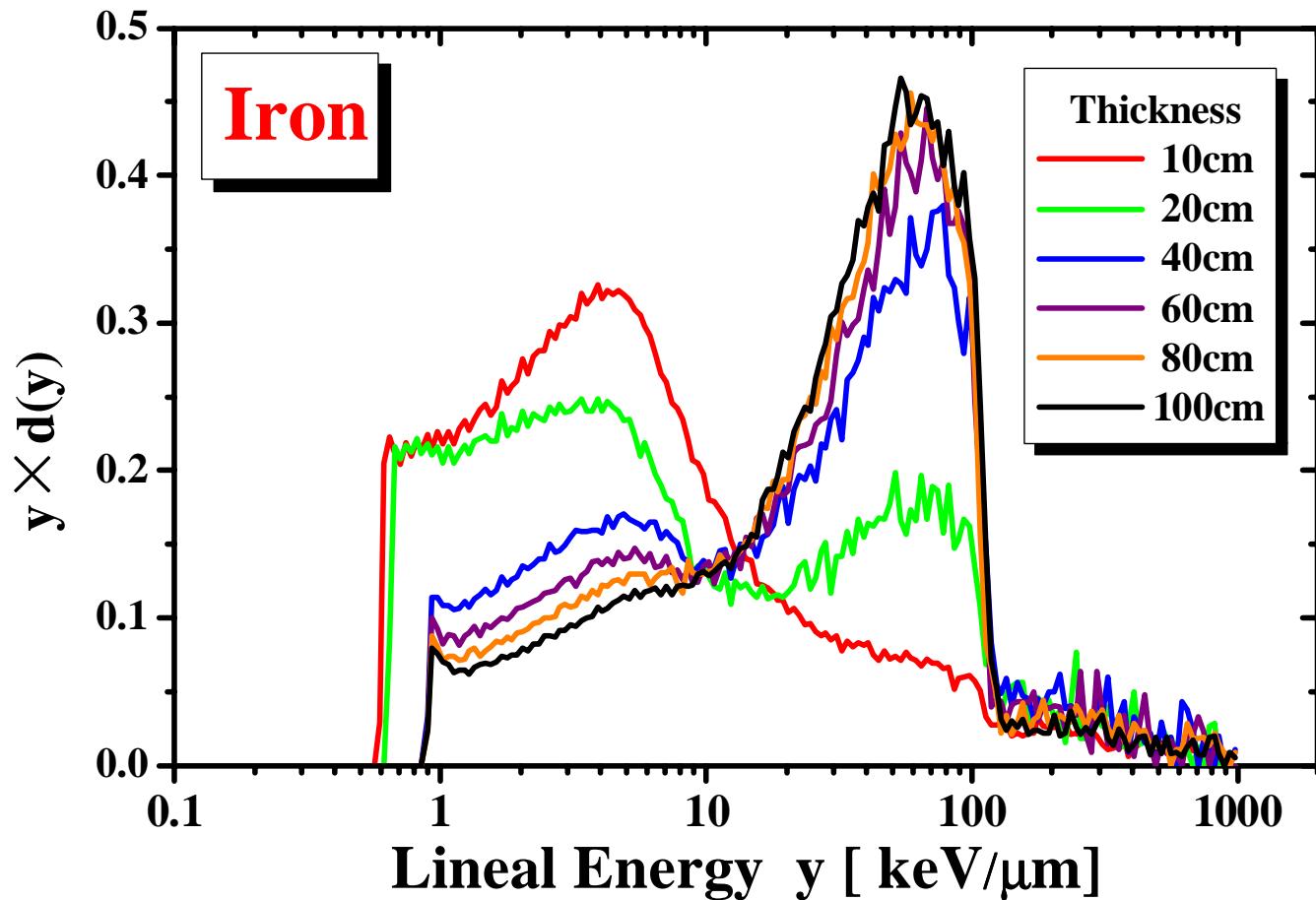
The y-distribution of absorbed neutron dose behind the **concrete** shield



Results(3)

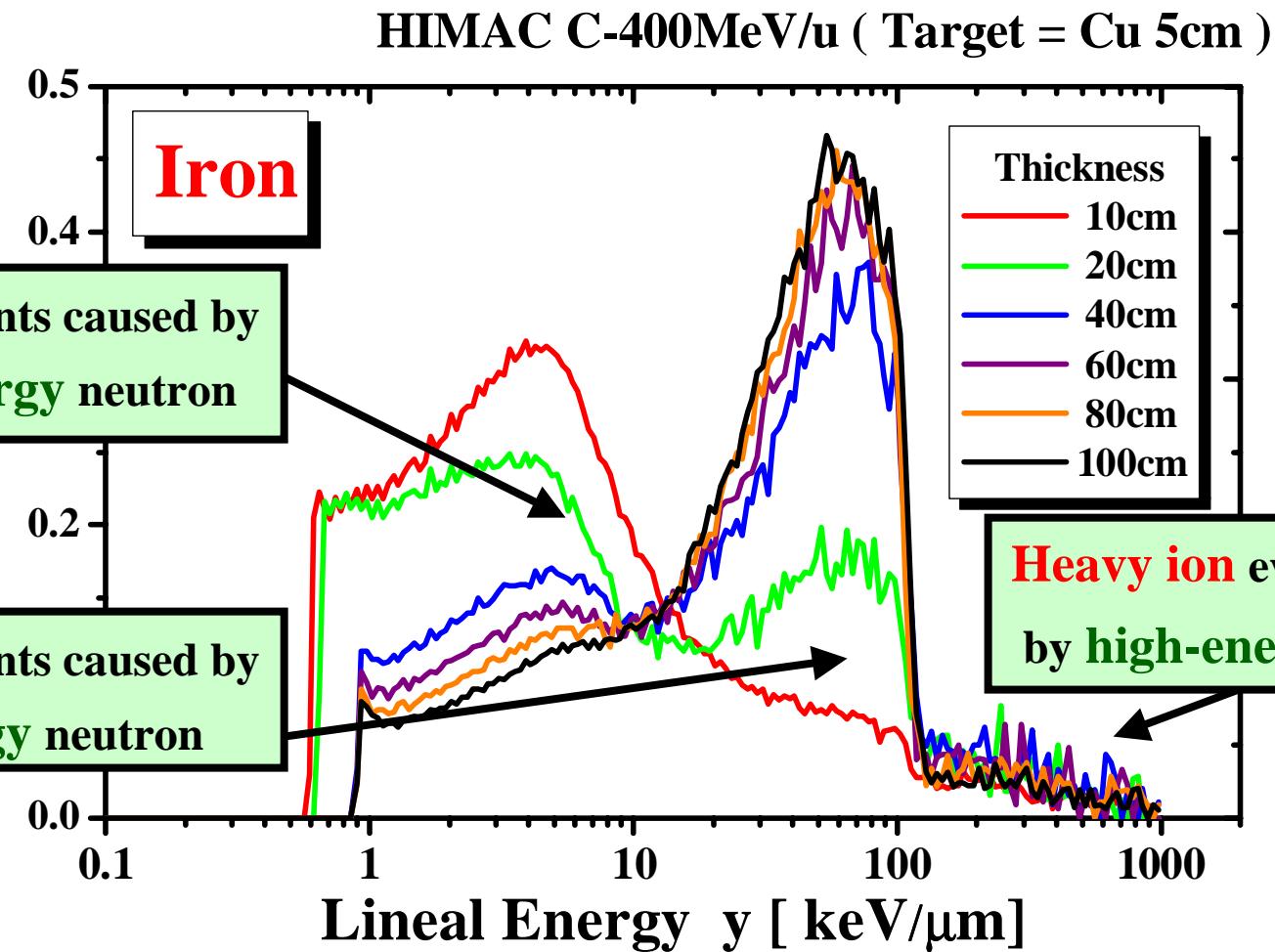
The y-distribution of absorbed neutron dose behind the Iron shield

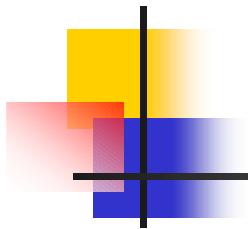
HIMAC C-400MeV/u (Target = Cu 5cm)



Results(3)

The y-distribution of absorbed neutron dose behind the Iron shield





The neutron dose behind the shield

The attenuation length λ

$$H_n = \frac{H_{n0}}{r^2} \exp\left(-\frac{d}{\lambda}\right)$$

H_n, H_{n0} : The absorbed neutron dose or dose equivalent [Gy,Sv]

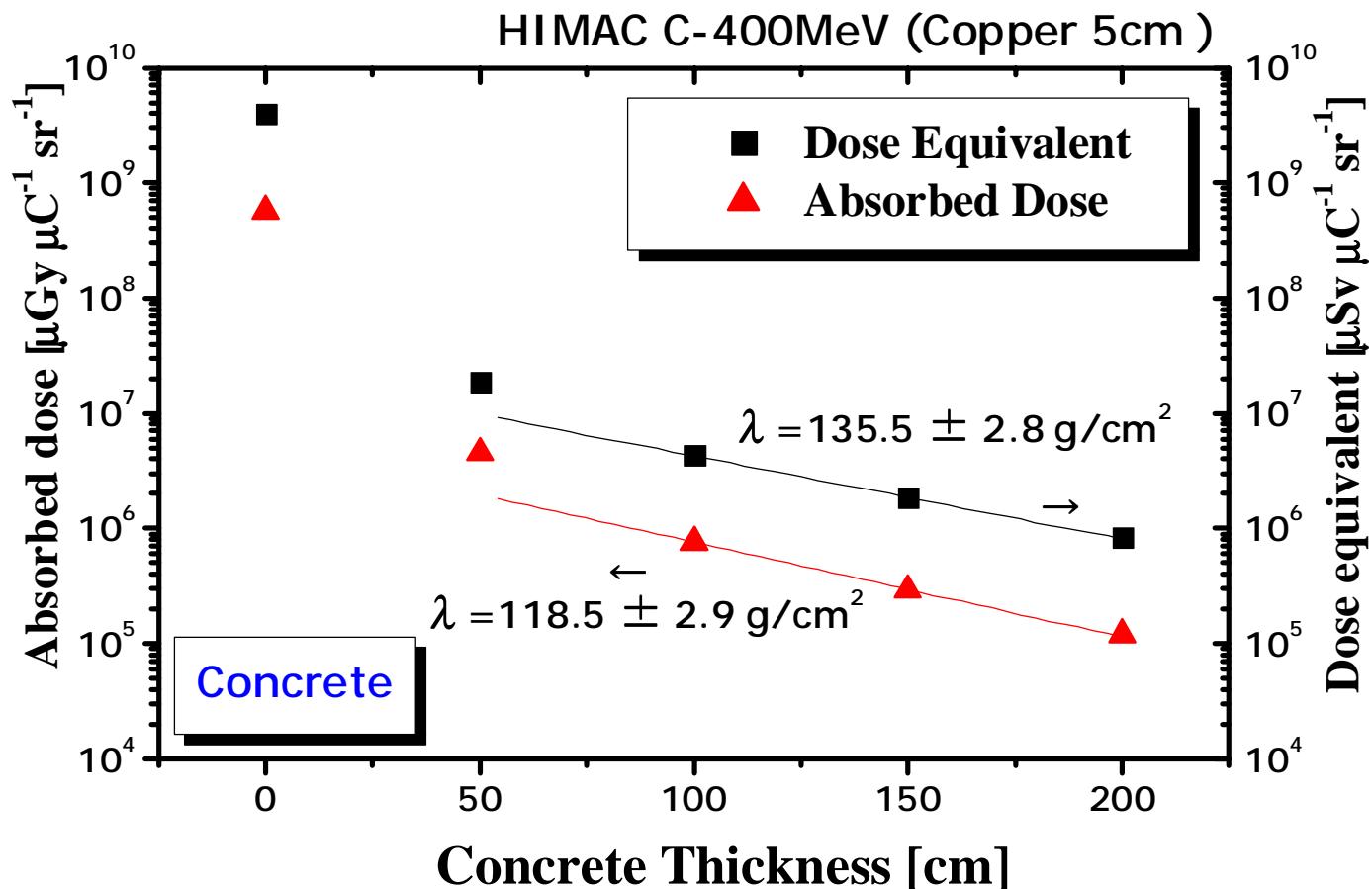
d : The shield thickness [g/cm²]

r : The distance between the target and detector [cm]

λ : The attenuation length [g/cm²]

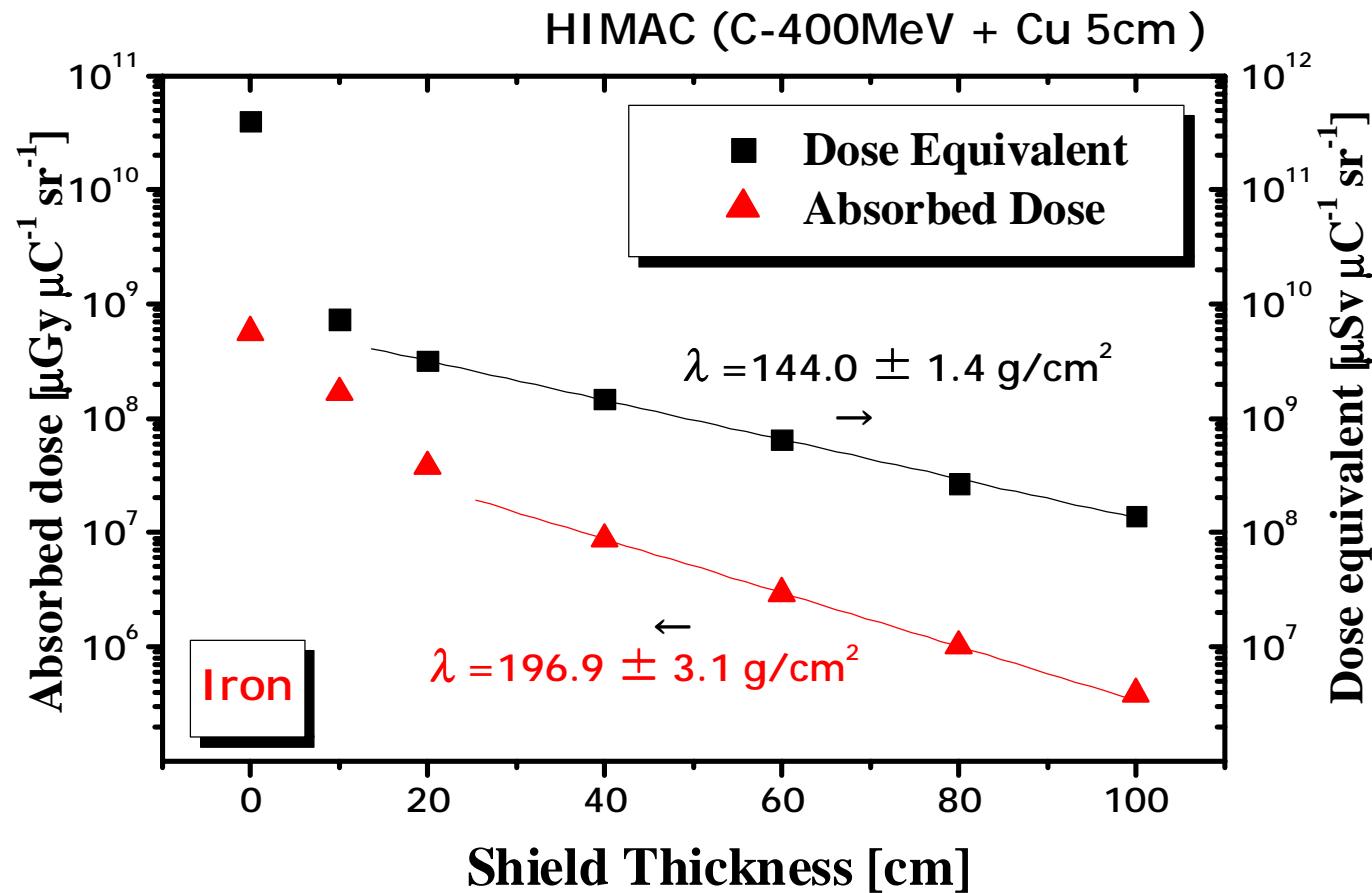
Results(3)

The attenuation profiles of neutron dose behind the **concrete** shield



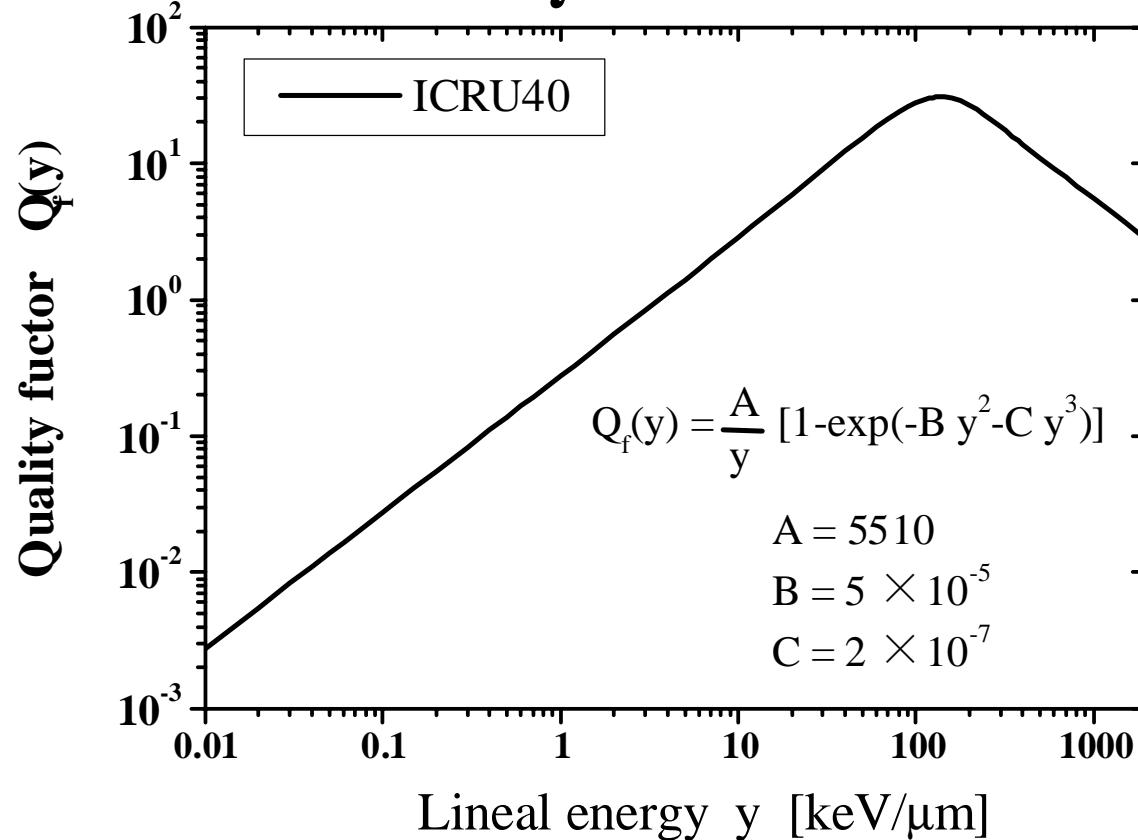
Result(3)

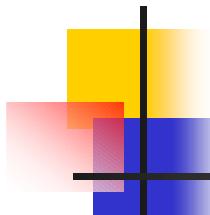
The attenuation profiles of neutron dose behind the iron shield



The neutron dose equivalent

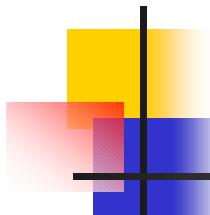
$$H = \int d(y)Q_f(y)dy$$





Conclusions(1-2)

- Experiment : FNL, TIARA
- Energy : 8, 250, 550 keV monoenergy at FNL
1, 2, 5, 6, 15 MeV monoenergy at FNL
65 MeV quasi-monoenergy at TIARA
- The **y-distribution** was obtained against the various neutron energy
- The neutron **detection efficiency** was obtained
- The neutron **dose sensitivity** was obtained and good agreement with the kerma value of the A-150



Conclusions(3)

- Experiment : HIMAC
- Particle : **C – 400 MeV/u**
- Target : **Cu 5 cm-thick**
- Shield thickness (cm)
 Concrete 50,100,150,200
 Iron 10, 20, 40, 60, 80, 100

- The changes of **y-distribution** was obtained behind the shield of various thickness
- The **attenuation length** of neutron dose was obtained
 - The absorbed neutron dose
$$\lambda = 118.5 \pm 2.9 \text{ [g/cm}^2\text{]}$$
$$\lambda = 144.0 \pm 1.4 \text{ [g/cm}^2\text{]}$$
 - The neutron dose equivalent
$$\lambda = 135.5 \pm 2.8 \text{ [g/cm}^2\text{]}$$
$$\lambda = 196.9 \pm 3.1 \text{ [g/cm}^2\text{]}$$

